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Magnetic Field Distribution due to Shielding in a Three-phase Source

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Abstract: A three-phase, 415 V magnetic field source was developed using coils to represent magnetic field from a substation. Magnetic field was then attenuated using three different planar shielding materials placed above the coils. RMS magnetic fields were measured at the intersections of a 100 by 100 mm grid drawn on the shielding materials. Shielding effectiveness was evaluated at each measured point. The results were then plotted in linear and contour plots. It was found that for the same applied magnetic field, shielding effectiveness was not constant and varied with distance from source. At some areas on the fringes of the shielding material, the shielding effectiveness was found to be less than unity, indicating an increase in magnetic field, probably due to flux leakage and concentration of flux lines at those areas. Of the three materials used, silicon steel was found to have the best shielding property with shielding effectiveness of greater than 4.5 for applied magnetic field of 250 μ T.

Key words: ELF magnetic field, material shielding, shielding effectiveness

INTRODUCTION

There is still concern among the general public of living near overhead transmission lines and substations. One of the causes for this is the public perception that electric and magnetic field from these sources could cause adverse health effect. Although research in this area had been done for more than thirty years, there is still no consensus among the scientific community as to whether long term, low dose exposure to power frequency magnetic field can cause adverse health effect. Many scientific reviews had been carried out and most of them concluded that the evidence supporting low-dose long-term exposure causing adverse health effect as weak and could not be used as guideline for imposing lower exposure values (WHO, 2007; ICNIRP, 1998).

There are several methods used to reduce magnetic field exposure from electric power facilities such as rearranging conductor phase configuration and compaction (Patterson, 1996; Tsanakas *et al.*, 2000; Said *et al.*, 2003). An alternative method that can be used is shielding. Shielding of magnetic field can be achieved by active shielding or passive shielding. Active shielding involves the use of current-carrying conductors whose magnetic field cancels the applied field. Passive shielding involves the use of materials that interact with power frequency magnetic fields such that the magnetic flux from the source is diverted into the magnetic shielding material and away from the region to be shielded or when currents

are induced in the shielding material by the magnetic field from the source and this in turn cause magnetic fields that partially cancel those of the source.

This study describes the results of experiments conducted to study magnetic field distribution and evaluation of shielding effectiveness of three shielding materials due to shielding of a three-phase source.

EXPERIMENTAL SET-UP AND MEASUREMENT PROCEDURE

The shielding experiment was conducted using test rig shown in Fig. 1. The test rig consisted of three coils placed in a wooden enclosure. Magnetic field from the coils were varied using a three phase variator. The coils were made from 2 mm enamel coated wires wound 82 turns on a 25 mm diameter, 95 mm long steel core. Two layers of coils were wound making a total of 164 turns. The three-phase coils were placed 150 mm apart and erected on a base of 480 by 680 mm. A wooden enclosure of 550 mm long, 240 mm wide and 130 mm high was then made to cover the coils to facilitate magnetic field measurements. Energy from the three-phase source was dissipated to a load bank consisting of coiled heaters.

Shielding materials of 800 mm long, 500 mm wide and 0.3 mm thick were placed on the wooden enclosure covering the coils. Shielding materials used were copper, galvanized iron and silicon steel of grade M5. Grid lines of 100 mm square with coordinates shown in Fig. 2, were

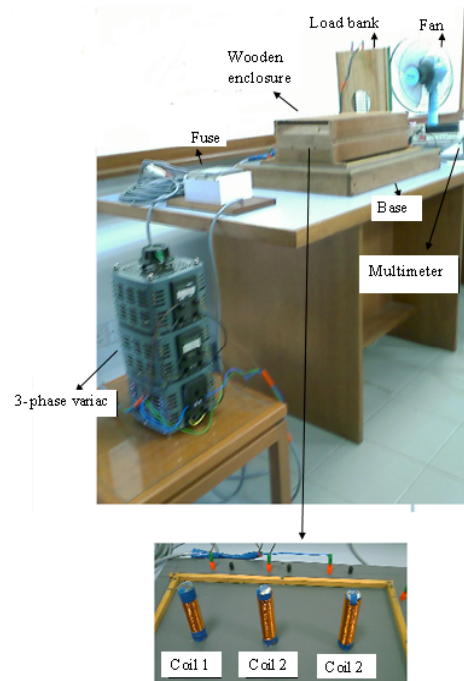


Fig. 1: Experimental set-up

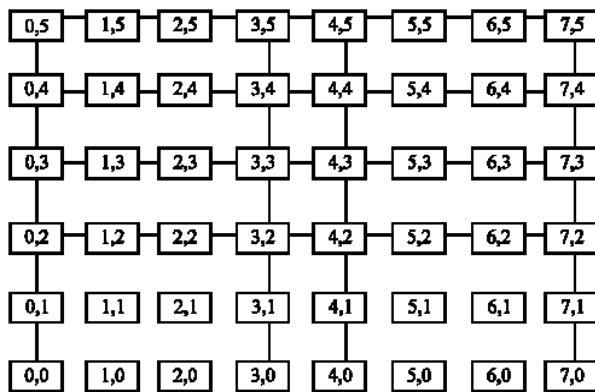


Fig. 2: Coordinates of grid lines, 100 by 100 mm drawn on shielding plates

drawn on the shielding material to indicate the locations where magnetic fields were measured. Magnetic field was measured using a three-axis EMDEX II meter.

The experiment started with calibration of the coils. The EMDEX II meter was placed on the wooden enclosure at the center of the coils. The variac was adjusted till a magnetic field reading of 50 μT was obtained on the meter. The current corresponding to this reading was noted. The variac was then adjusted to obtain magnetic field readings of 100, 150, 200, 250 and

Table 1: Calibration of three phase coils

Magnetic flux density (μT)	Current (A)
50	0.190
100	0.428
150	0.633
200	0.907
250	1.075
300	1.303

300 μT and the current corresponding to each reading was noted. The result is as shown in Table 1.

A thin plywood, with grid lines of 100 mm square drawn on it, was then placed on top of the wooden enclosure above the coils. The variac was then adjusted to obtain current reading corresponding to 50 μT . Magnetic field readings were then measured at the 48 locations on the coordinates of the grid lines. This process was then repeated for magnetic fields of 100, 150, 200, 250 and 300 μT . The experiments were then repeated for all the shielding materials namely, copper, galvanized iron and silicon steel.

RESULTS AND DISCUSSION

Table 2 shows a sample result obtained with applied field of 250 μT for no-shield and with 0.3 mm plates of copper, galvanized iron and silicon steel as shielding materials. To provide meaningful presentation of field

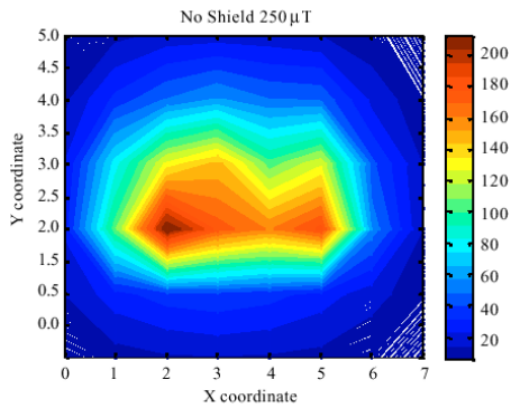


Fig. 3: Contour plot for no-shield, and applied field of 250 μT

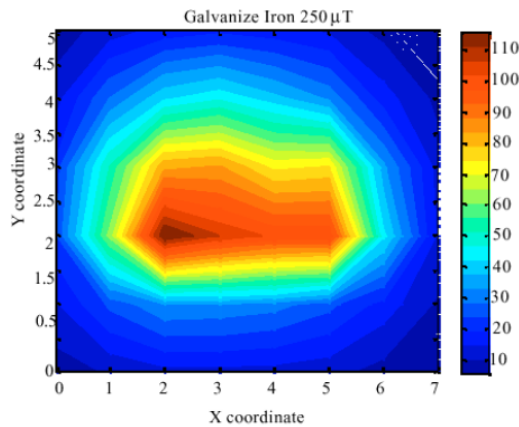


Fig. 4: Contour plot for galvanized iron with applied field of 250 μT

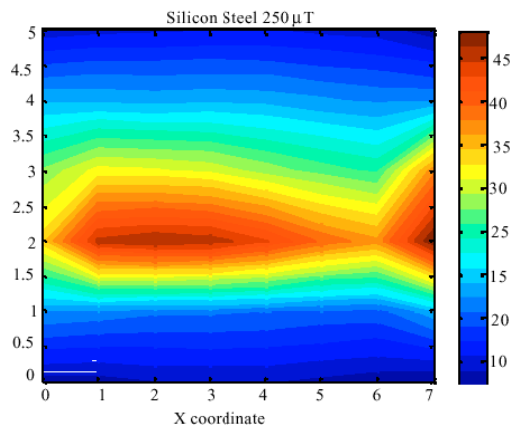


Fig. 5: Contour plot for silicon steel with applied field of 250 μT

distribution, the data collected were plotted in contour plots as shown in Fig. 3-5.

From Fig. 3-5 it can be seen that the magnetic field pattern above the coils were similar, with high magnetic

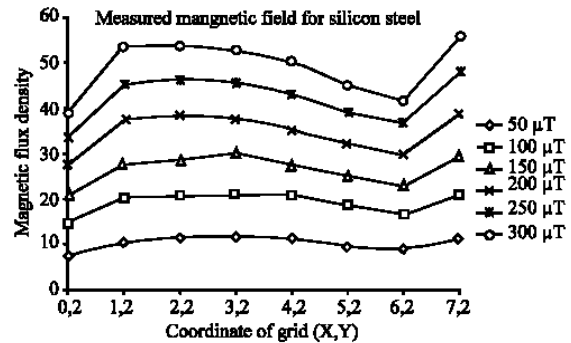


Fig. 6: Measured magnetic field using 0.3 mm silicon steel for various applied fields

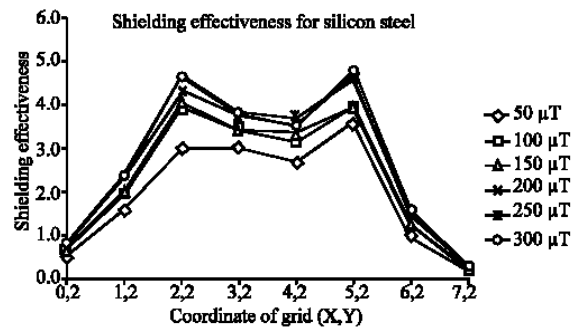


Fig. 7: Shielding effectiveness for 0.3 mm silicon steel for various applied field

fields along the y-axis at $y = 2$ and magnetic field reduction to around 40% along the y-axis at $y = 1$ and $y = 4$. The magnitudes of magnetic fields were different for different shielding materials.

The measure of amount of shielding afforded by shielding material is Shielding Effectiveness (SE). It is defined as the ratio of magnetic field at a point without shielding to the magnetic field at the same point with shielding. Shielding effectiveness for the three materials used were evaluated and a sample result for applied magnetic field of 250 μT is shown in Table 3.

To see the effect of varying applied field on measured magnetic field and shielding effectiveness, the results at coordinates $y = 2$ for silicon steel with applied field variations of 50 to 300 μT are shown in Fig. 6 and 7, respectively. From Fig. 6 it can be seen that shielded magnetic field changed in proportion to the applied field while Fig. 7 shows that the shielding effectiveness being highest at regions of strong magnetic fields (areas nearest the coils) and lowest further away. Shielding effectiveness was less than 1 at areas near the fringes of the shield material indicating an increase in magnetic field when compared to magnetic field measurement with no shielding. Figure 8 shows shielding

Table 2: Measured magnetic field with applied field of 250 μ T

Coordinate of grid	Magnetic (μ T)			
	No shield	Copper	Gal.iron	Silicon steel
0,0	7.2	7.2	7.70	8.4
2,0	13.0	13.3	12.90	9.2
4,0	13.8	14.0	12.30	9.3
5,0	11.6	11.7	11.40	8.8
6,0	9.0	8.8	8.30	8.3
0,1	14.6	15.2	14.00	17.7
2,1	36.0	39.1	32.70	16.3
4,1	35.0	33.9	30.50	16.0
6,1	17.7	15.8	17.40	15.3
0,2	24.8	28.5	23.20	33.6
2,2	212.8	216.8	116.00	46.3
4,2	159.2	147.2	100.80	43.2
6,2	54.4	42.2	43.20	36.8
0,3	21.4	23.0	2.05	28.0
2,3	128.0	131.2	82.40	31.3
4,3	103.2	104.8	72.80	28.7
6,3	42.4	38.4	34.20	25.6
0,4	12.2	13.1	12.60	19.1
2,4	49.6	55.2	41.20	18.7
4,4	49.6	48.8	39.20	18.6
6,4	20.1	18.9	16.60	17.3
0,5	6.6	6.7	7.50	9.6
2,5	17.0	18.1	16.60	10.6
4,5	16.7	17.5	16.00	10.9
6,5	9.2	9.5	8.50	9.9

Table 3: Shielding effectiveness for applied field of 250 μ T

Coordinate of grid	SE for applied field of 250 μ T		
	Copper	Gal. iron	Silicon steel
0,0	1.0	0.9	0.9
2,0	1.0	1.0	1.4
4,0	1.0	1.1	1.5
5,0	1.0	1.0	1.3
6,0	1.0	1.1	1.1
0,1	1.0	1.0	0.8
2,1	0.9	1.1	2.2
4,1	1.0	1.1	2.2
6,1	1.1	1.0	1.2
0,2	0.9	1.1	0.7
2,2	1.0	1.8	4.6
4,2	1.1	1.6	3.7
6,2	1.3	1.3	1.5
0,3	0.9	1.0	0.8
2,3	1.0	1.6	4.1
4,3	1.0	1.4	3.6
6,3	1.1	1.2	1.7
0,4	0.9	1.0	0.6
2,4	0.9	1.2	2.7
4,4	1.0	1.3	2.7
6,4	1.1	1.2	1.2
0,5	1.0	0.9	0.7
2,5	0.9	1.1	1.6
4,5	1.0	1.0	1.5
6,5	1.0	1.1	0.9

effectiveness evaluated at a single point, coordinate 2, 2 where measured magnetic field was found to be highest. It shows variation of shielding effectiveness for all the three materials used with different applied field.

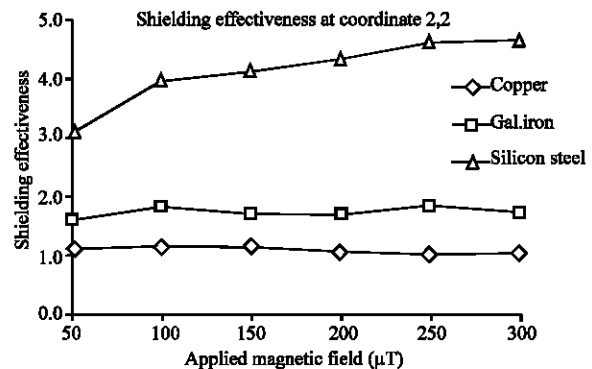


Fig. 8: Shielding effectiveness at coordinate 2,2 for different materials and applied magnetic field

CONCLUSION

This study had shown that magnetic field distribution due to shielding in a given three phase source is generally the same but with different shielding effectiveness for different material and applied field. Shielding effectiveness for the same material is not constant and depends on the magnetic field on which it is exposed to. This is probably due to the non-linearity of the B-H curve of the material. Magnetic field can be increased at the fringes of the shielding material, probably due to concentrations of flux lines at the edges.

Increasing the length of the shielding material could reduce this. For the range of applied 50 Hz. field in this experiment, copper did not provide any shielding. Silicon steel, of grade M5, gave the best shielding property with shielding effectiveness of 3 for applied field of 50 μ T and 4.5 for applied field of 300 μ T.

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